Where Complication Produces Better Machines

Andrew Murray

We're fascinated by complicated mechanical systems. Consider the clockworks and the automaton in the movie *Hugo* or the reconfigurations that turn a trailer truck into Optimus Prime in *Transformers*. Both movies display incredibly complicated systems whose interlocking parts reliably create a mechanical dance. There's a Rube Goldberg-like cause and effect where A drives B moving C, yet there is also a sense that there is no chance involved and they will produce the required motions over and over. Occasionally, mechanisms of the complexity of an automaton are actually designed, built, and reliably work, but the process can be painstakingly long and rely on the sophisticated mechanical insight of lone designers.

In the University of Dayton's Design of Innovative Machines Lab (DIMLab), we are working to systematize the design of complicated mechanical systems. One focus in the DIMLab is designing rigid-body shape-changing devices. These devices combine some fairly simple parts, links, hinges and sliders to be exact, into some sophisticated machines. We have toyed with shape-changing spoilers, wings, seats, cams and parabolic light reflectors. We can even mechanically transform a "U" into a "D" and have built the prototype to watch it happen. The idea is simple: If someone can draw a set of curves on a sheet of paper, we want to be able to design a mechanism that matches those curves.

The National Science Foundation has funded the most practical implementation we have so far for rigid-body shape-change, designing variable geometry dies for polymer extrusion. A host of everyday parts, from PVC tubing to weather stripping to artificial lumber for decking, is made by heating plastic and forcing it through a hole. Creating a part this way is called extrusion. Extrusion is so valued because it is inexpensive and fast when compared to molding, the other primary way of making plastic parts. So why aren't more parts extruded instead of molded? Note that in every one of the extrusion examples the cross-section never changes. The PVC tubing looks the same no matter where you cut it. A variable geometry die allows the cross-section to vary. Simply speaking, the pipe can change diameter. Or, the pipe can go from circular to square. Looking forward, maybe we can extrude utensils or chess pieces or fan blades. In the DIMLab, we are developing the design algorithms to produce these dies, and have now prototyped and tested a variety of simple examples.

Rigid-body shape-change can also be applied outside of machine design. We are working with scientists in France to apply it to morphometry, or systematically measuring changes in shape. Morphometry is frequently used to study changes due to evolution and growth. In our case, we are analyzing skull growth in children that have experienced head trauma resulting in skull deformation. This aspect of the research is decidedly non-mechanical, but it does show the utility in viewing shapes as complicated collections of links, hinges and sliders.

In some cases, the DIMLab has adopted the strategy that the more moving parts we have the better. We have developed procedures that allow mechanisms to grow to an arbitrary number of links to solve design challenges. In some cases, our mechanisms have grown to include dozens of components, where the action of any one of the parts affects the motion of all others. The result is mechanisms that captivate the imagination yet possess almost no capacity to be designed and built.

Can we design Optimus Prime or an automaton systematically yet? It would be nice if we could just draw a few curves and apply some fancy design algorithms and get them, but we can't. We can, however, take a few curves and sometimes create useful mechanisms, sometimes create complicated mechanisms, and sometimes create mechanisms that are both useful and complicated.